

BELLCOMM, INC.

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SUBJECT: Supplementary Heating Requirements
for an S-IVB Workshop with Inertial
or Gravity-Gradient Stabilization -
Case 600-3

DATE: July 3, 1967**FROM:** D. J. BelzABSTRACT

When deployed in orbit, the S-IVB Workshop will be subjected to several sources of heating: direct solar and earth radiation; heat generated internally by electrical equipment; and heat generated metabolically by the crew. Interior temperatures must satisfy constraints imposed by experiments and crew comfort. If heat sufficient to maintain acceptable temperatures is not available from external radiant and internal "waste" sources, auxiliary (electrical) heating will be required.

This memorandum analyzes currently available information to determine the electrical power requirements for auxiliary heaters in the Workshop. It is shown that a potential saving of 1100 to 1200 watts in the Workshop electrical power requirement can be effected by employing inertial as opposed to gravity-gradient stabilization of the vehicle in orbit.

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MEMORANDUM FOR FILE

1.0 INTRODUCTION

When deployed in orbit, the S-IVB Workshop will be subjected to several sources of heating: direct solar radiation; earth-emitted and earth-reflected radiation; waste heat generated internally by experiment equipment, ECS fans, lights; and heat generated metabolically by the crew. The Workshop's thermal balance thus depends upon a number of parameters such as spatial orientation, inclination of the orbital plane to the ecliptic plane, crew and equipment timelines, electrical power availability, and the overall thermal design of the Workshop itself. Interior temperatures must satisfy constraints imposed by experiments and crew comfort. If heat sufficient to maintain acceptable temperatures is not available from external radiant and internal "waste" sources, auxiliary heating will have to be provided. Such an additional thermal input would likely be powered by the Cluster EPS.

This memorandum analyzes currently available information to determine the electrical power requirements for auxiliary heaters in the Workshop during Mission A. These requirements are indicated for both a gravity-gradient stabilized vehicle and an inertially oriented vehicle.

2.0 WORKSHOP THERMAL CONTROL CONCEPT

The Airlock Module's ECS will circulate and replenish an oxygen-nitrogen atmosphere to the Workshop at a total pressure of 5 psia and an initial temperature between 45°F and 50°F. The circulating atmosphere is drawn by eight fans into the Workshop through ducts which in turn feed eight plenum chambers spaced circumferentially about the Workshop interior at the base of the S-IVB forward dome. Each plenum chamber forces O_2/N_2 through two thermal control ducts each of which has a cross-section approximately 1 1/2" by 40 to 62 inches, and which leads aft approximately 20 feet to the vicinity of the S-IVB common bulkhead.* Variable heat transfer through the LH_2

*The common bulkhead separates the S-IVB LH_2 and LOX tanks.

tank wall is provided by individually activating the eight fans. The atmosphere leaving the ducts is mixed with the bulk atmosphere and drawn forward toward the Airlock ECS inlet and recirculating ducts.

The Airlock ECS removes latent heat from the atmosphere in the process of condensing water vapor to control humidity. Removal of CO_2 , odors, and particulate contaminants is also performed by the Airlock ECS. The primary mechanism for rejection of sensible heat from the Workshop is by passive conduction through the cylindrical walls and radiation to space; the forward dome and S-IVB aft structure will be covered with 15 layers and 10 layers, respectively, of high performance insulation to reduce the overall heat loss.**

3.0 WORKSHOP TEMPERATURE REQUIREMENTS

The Medical Research and Operations Directorate at MSC has defined crew comfort criteria which in part call for atmospheric temperatures within the range 60°F to 100°F and humidity with a minimum water vapor partial pressure (PH_2O) of 8 mmHg and a maximum relative humidity of 95% (Ref. 2). Condensation of atmospheric water vapor on exposed surfaces within the Workshop presents at least two potential problems: (1) Excessive condensation may "dry" the atmosphere to the point where the ECS latent heat exchanger's ability to remove atmospheric moisture is impaired; (2) Condensation within thermal control ducts and in other relatively inaccessible places may provide an environment in which bacteria and fungi can grow unchecked.

At the minimum partial pressure of water vapor (8 mmHg), H_2O will condense onto surfaces colder than 46.4°F . Thus, if the PH_2O in the thermal control ducts can be maintained at or slightly above 8 mmHg, wall temperatures need not be heated to temperatures more than somewhat above 46.4°F to avoid condensation. The degree to which this humidity control can be achieved is not certain; nevertheless for purposes of calculating heating requirements within the Workshop, it will be assumed that a minimum wall temperature of 50°F is to be maintained to avoid condensation. A "nominal" atmospheric temperature of 70°F within the Workshop will be assumed together with a physiologically determined "minimum" gas temperature of 60°F .

**Average heat losses of 5265 Btu/Hr and 1780 Btu/Hr through the forward and aft domes can be reduced to 200 Btu/Hr in each location by high performance insulation as described above (Ref. 1).

4.0 INTERNAL HEATING REQUIREMENTS TO MAINTAIN MINIMUM WORKSHOP TEMPERATURES

4.1 GRAVITY GRADIENT STABILIZED VEHICLE

Rates of internal heat generation required to maintain various temperature levels within a gravity-gradient stabilized Workshop have been calculated in Reference 2. The Workshop orbit is assumed to be circular with an altitude of 260 nautical miles and an inclination to the equatorial plane of 28.5° . Precession of the spacecraft orbital plane occurs at the rate of $6.5^\circ/\text{day}$. Maximum external heating occurs when the orbital plane is inclined 52° from the ecliptic plane while being normal to a plane defined by the Earth's rotation axis and the Earth-Sun line ($\beta = 52^\circ$). Minimum external heating occurs when the Earth-Sun line lies within the Workshop orbital plane ($\beta = 0$). These extreme conditions can be said to define "hot" and "cold" orbits respectively.

Required heating rates are averaged over a given orbital period; variations in Workshop internal temperatures during a single orbit are not expected to exceed 5°F . It is assumed that a meteoroid bumper will cover essentially all of the S-IVB LH_2 tank cylindrical wall and that high performance insulation, as described previously, will be applied to the forward dome and aft structure to reduce forward and aft heat leaks. Emissivities of 0.8 are assumed for interior partitions forming crew-quarters floors and ceiling, as well as the curtains which form the longitudinal thermal ducts. An average emissivity of 0.5 is assumed for the fire-retardant liner of the LH_2 tank. The exterior of the meteoroid bumper is assumed to be black ($\alpha_s = \epsilon = 0.9$).

Table 1 indicates the total internal heat generation required to maintain the indicated Workshop internal temperatures.

TABLE I. TOTAL INTERNAL HEAT GENERATION (Q) REQUIRED TO MAINTAIN DESIRED TEMPERATURES FOR A GRAVITY GRADIENT STABILIZED WORKSHOP*

	Q FOR 600F (MINIMUM) ATMOSPHERIC TEMPERATURE		Q FOR 700F (NOMINAL) ATMOSPHERIC TEMPERATURE		Q FOR 500F (MINIMUM) INSIDE WALL TEMPERATURE	
	BTU/HR	WATTS	BTU/HR	WATTS	BTU/HR	WATTS
"COLD" ORBIT ($\beta = 0^\circ$)	4000	1170	4880	1430	7130	2080
"HOT" ORBIT ($\beta = 52^\circ$)	1570 (A)	460 (A)	3640 (A)	1070 (A)	5000	1460

*BASED ON CALCULATIONS REPORTED IN REFERENCES 2, 3.

NOTE: A - NO CIRCULATION IN DUCTS OF FAN AT CENTER OF "SHADOW" SIDE OF WORKSHOP.

4.2 INERTIALLY STABILIZED VEHICLE

Preliminary calculations of internal heat generation (Q) required to achieve desired temperatures in an inertially stabilized Workshop are presented in this section. Table 2 indicates that for $\beta = 0^\circ$, a minimum of 1000 Btu/Hr (293. watts) is required to maintain a nominal bulk atmospheric temperature of 70°F . At this value of Q, the corresponding minimum wall temperature is $\sim 40^\circ\text{F}$, indicating that condensation will occur in the thermal control ducts. For the same orbit, a minimum wall temperature of 50°F can be maintained with 3000 Btu/Hr (880. watts) by shutting off ECS fans directly exposed to the Sun; the corresponding bulk atmospheric temperature within the Workshop is 80°F .

For $\beta = 52^\circ$, 1000 Btu/Hr (293 watts) can maintain a 50°F wall temperature; the atmospheric temperature in that case will be approximately 80°F .

TABLE 2. TOTAL INTERNAL HEAT GENERATION (Q) REQUIRED TO MAINTAIN DESIRED TEMPERATURES FOR AN INERTIALLY STABILIZED WORKSHOP*

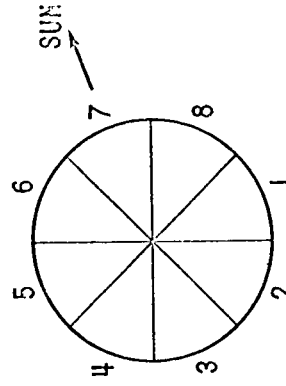
	Q FOR 70°F (NOMINAL) ATMOSPHERIC TEMPERATURE		Q FOR 50°F (MINIMUM) WALL TEMPERATURE	
	BTU/HR	WATTS	BTU/HR	WATTS
$\beta = 0^\circ$	1000 (A)	293 (A)	3000 (B,C)	880 (B,C)
$\beta = 52^\circ$	<1000 (A,C)	<293 (A,C)	1000 (A,C)	293 (A,C)

NOTES: A - FANS 6, 7, 8 ON HIGH SPEED

B - FANS 6, 7, 8 OFF

C - BULK ATMOSPHERIC TEMPERATURE IS 80°F FOR THIS CASE

* BASED ON CALCULATIONS REPORTED IN REFERENCE 3.



5.0 ANTICIPATED INTERNAL HEAT GENERATION

Heat generation rates within the Workshop will vary widely with equipment utilization, crew activity, lighting levels, and the number of ECS fans in operation. A realistic timeline of internal heat generation is not available at this writing; a rough estimate of anticipated internal heat generation is, however, presented in Table 3. None of the entries in that table is precisely defined at the moment; as pointed out by the author in Reference 4, MSC Flight Operations is in the process of defining Workshop crew time-lines for Mission A from which MSC/MR and O will estimate metabolic thermal profiles. This activity is scheduled for completion during the first week of July 1967.

Whether all lights will be extinguished and both crew members evacuated from the Workshop during periods of minimum activity as assumed in this memorandum has not yet been determined. It is assumed, however, for purposes of establishing the lowest likely minimum that the only internal heat source during such periods will be 250 Btu/Hr (73 w.) from fans required to maintain atmospheric circulation.

TABLE 3. AVERAGE HEAT GENERATION RATES DURING PERIODS OF
MAXIMUM AND MINIMUM ACTIVITY WITHIN THE WORKSHOP

	MAXIMUM WORKSHOP ACTIVITY (14 HOURS/DAY)		MINIMUM WORKSHOP ACTIVITY (10 HOURS/DAY)	
	BTU/HR	WATTS	BTU/HR	WATTS
EQUIPMENT				
EXPERIMENTS	1700.	500.	0.	0.
FANS	550.	161.	250.	73.
LIGHTS	1400.	410.	0.	0.
EQUIPMENT SUBTOTAL	3650.	1070.	250.	73.
METABOLIC (2 MEN)	1100.	322.	0.	0.
TOTAL	4750.	1390.	250.	73.

AVERAGE HEAT LOAD DURING A GIVEN DAY IS 2870. BTU/HR (842. WATTS).

6.0 COMPARISON OF THERMAL REQUIREMENTS WITH ANTICIPATED INTERNAL HEAT GENERATION

A preliminary estimate of auxiliary heating required to maintain Workshop temperatures at acceptable levels is shown in Tables 4 and 5. It is assumed that minimum temperature requirements are applicable at all times during Mission A regardless of whether crew members are in or out of the Workshop at any given time; to assume otherwise would in some cases restrict the movement of astronauts into the Workshop while temperatures are being raised.

6.1 GRAVITY-GRADIENT STABILIZED VEHICLE

Table 4 indicates that 6880 Btu/Hr (2010. w) of auxiliary thermal power may be required to prevent condensation on Workshop walls during periods of minimum activity in cold orbits.* If condensation is accepted in the design, then at least 3750 Btu/Hr (1100. watts) of auxiliary heating will be required to maintain a bulk atmospheric temperature of 60°F during periods of minimum Workshop activity in cold orbits. If no auxiliary heat is provided during maximum activity periods, Workshop atmospheric temperatures will remain above 60°F, but atmospheric water vapor will condense on the walls. If no auxiliary heat is provided during periods of minimum activity, atmospheric temperatures will fall below 60°F and water will condense on the walls during both "cold" and "hot" orbits.

*If water vapor does condense on a cold surface it may be removed by transporting it through wicking to a warmer region of the Workshop and there evaporated back into the cabin atmosphere. This memorandum considers a "worst case" situation in that initial condensation is avoided by the nominal 50°F wall temperature, provided the partial pressure of water vapor in the atmosphere adjacent to a "cold" wall does not greatly exceed 8 mmHg.

TABLE 4. PRELIMINARY ESTIMATE OF AUXILIARY HEAT-RATES (H) REQUIRED TO MAINTAIN DESIRED TEMPERATURES IN A GRAVITY GRADIENT STABILIZED WORKSHOP

		H FOR 60°F (MINIMUM) ATMOSPHERIC TEMPERATURE BTU/HR (WATTS)	H FOR 70°F (NOMINAL) ATMOSPHERIC TEMPERATURE BTU/HR (WATTS)	H FOR 50° INSIDE WALL TEMPERATURE BTU/HR (WATTS)
"COLD" ORBIT $\beta = 0^\circ$	MAXIMUM WORKSHOP ACTIVITY	-750. (-220.)	+130. (+38.)	+2380. (+697.)
	MINIMUM WORKSHOP ACTIVITY	+3750. (+1100.)	+4630. (+1350.)	+6880. (+2010.)
"HOT" ORBIT $\beta = 52^\circ$	MAXIMUM WORKSHOP ACTIVITY	-3180. (-930.)	-1110. (-325.)	+250. (+73.)
	MINIMUM WORKSHOP ACTIVITY	+1320. (+387.)	+3390. (+993.)	+4750. (+1390.)

6.2 INERTIALLY STABILIZED VEHICLE

Table 5 indicates that 2750. Btu/Hr (805 watts) of auxiliary thermal power are required within the Workshop to maintain a minimum wall temperature of 50°F during periods of minimum activity with $\beta = 0$. In the same orbit, a nominal 70°F bulk atmospheric temperature can be achieved with 750 Btu/Hr (220. watts) of auxiliary heating during minimum activity periods, although condensation will then occur.

For $\beta = 52^\circ$, 750 Btu/Hr (220. watts) of auxiliary thermal power will maintain a 50°F wall temperature and an above nominal cabin atmospheric temperature with minimum Workshop activity.

During maximum activity periods, no auxiliary heating is required to maintain a 50°F minimum wall temperature and nominal &70°F) atmospheric temperature.

TABLE 5. ESTIMATE OF AUXILIARY HEAT-RATES (H) REQUIRED TO MAINTAIN DESIRED TEMPERATURES IN AN INERTIALLY STABILIZED WORKSHOP

		H FOR 70°F (NOMINAL) ATMOSPHERIC TEMPERATURE		H FOR 50°F (MINIMUM) WALL TEMPERATURE	
		BTU/HR	WATTS	BTU/HR	WATTS
$\beta = 0^\circ$	MAXIMUM WORKSHOP ACTIVITY	-3750	-1100	-1750	-513
	MINIMUM WORKSHOP ACTIVITY	+750	+220	+2750	+805
$\beta = 52^\circ$	MAXIMUM WORKSHOP ACTIVITY	<-3750	<-1100	-3750	-1100
	MINIMUM WORKSHOP ACTIVITY	<+750	<+220	+750	+220

7.0 CONCLUSIONS

The preceding sections of this memorandum provide a preliminary basis for comparing the electrical heater requirements of an inertially stabilized Workshop with a gravity-gradient stabilized Workshop. That comparison may be summarized as follows:

1. During periods of maximum activity (14 hours/day) an inertially stabilized Workshop requires no auxiliary heating to maintain a nominal 70°F bulk atmospheric temperature and 50°F minimum wall temperature regardless of the value of β , whereas with gravity-gradient stabilization, auxiliary heaters with outputs of ~ 40 . watts or ~ 700 . watts, respectively, are required to maintain those temperatures for $\beta = 0^\circ$.*
2. During periods of minimum activity as defined in this memorandum, a 70°F cabin atmospheric temperature or 50°F wall temperature can be maintained for any value of β with 220. watts or 805. watts, respectively, of auxiliary heater power in an inertially stabilized vehicle while the corresponding requirements for a gravity-gradient stabilized Workshop are 1350. watts or 2010. watts respectively.

*A 50°F wall temperature is used herein as a criterion for no condensation of water vapor on the Workshop's walls. As pointed out previously, this criterion is valid only if the PH_2O adjacent to the walls can be kept at or only slightly above the minimum physiological requirement of 8 mmHg.

3. If all heat dissipation for thermal control during minimum activity periods is to be provided by electrical power dissipation, the total electrical power requirement for the Workshop during such periods in the "worst" orbital positions is as shown below:

	70°F Bulk Atmos- pheric Temperature	50°F Minimum Wall Temperature
Inertial Stabilization	293. w.	880. w.
Gravity-Gradient Stabilization	1430. w.	2080. w.

Therefore, based on the preceding analysis, a potential saving of 1100. to 1200. watts in the Workshop electrical power requirement can be effected by employing inertial as opposed to gravity-gradient stabilization.

1022-DJB-dlb

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